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CNA Research Contribution No. 21

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ABSTRACT

Two principal dimensions of system cost analysis are addressed. First, the comparative analysis of alternative systems requires a method of structuring and synthesizing cost estimates in order to reveal both the total costs of achieving effectiveness and the significant differences to be found among various force-mixes. Second, the methods of estimating particular costs are evolving from a history of inappropriate or inaccessible data and great uncertainty concerning the time and cost of ultimately achieving demonstrated capability. Several important avenues for further work are discussed.

COSTING FOR SYSTEMS ANALYSIS

A systems analysis, or its quantitative portion which is often called a cost-effectiveness analysis, compares alternative system proposals for achievement of a mission and attempts to discover which, on quantitative grounds, is preferred. Less ambitiously, it reveals those variations that are decidedly inferior and assists in avoiding gross inefficiencies. It examines a part of the defense forces. A partial study cannot, by itself, determine the appropriate level of mission achievement, but by evaluating force-mixes at each of several plausible levels within the mission it assists the "higher-order" comparison among levels of alternative programs.

THE ROLE OF COST

In assessing alternatives, the procedure may take either one of two fundamental forms. A desired level of effectiveness may be specified and the analysis seeks the way to achieve it most economically; or a level of expenditure may be specified and the analysis explores the effectiveness provided by system variations.

In most cases there are several meaningful elements of achievement in the objective. In a non-marketable activity, such as defense, these positive achievements within a mission are not readily represented by dollar magnitudes, or by any other single common denominator, for the purpose of specifying a level of an activity. For this reason, the specified cost (fixed-budget) procedure is often employed. This does not provide a means of evaluating the relative desirability of the several elements of achievement in the mission; it merely permits translation from the measurement of resources to the measurement of effectiveness elements, for each system examined, in order to advance sensible comparisons and selections.

Why should the compared force-mixes be structured deliberately to be equal in cost (or effectiveness)? The answer is straightforward, - if system or force I is demonstrably more effective than II and also costs more than II, we cannot determine from this information whether I's greater effectiveness results simply from a larger scale of expenditure, or from a more productive mixture of resources and operational methods, or both. However, if their cost is equal, the more effective alternative is clearly preferred. In terms of economic analysis, the study at this stage attempts to locate a point on the total cost function, - with cost as a function of output (effectiveness).

It is often appropriate to define a bench-mark force for the postulated budget. In a study to assist future procurements for a current mission, one bench-mark may be taken as a current financial program with systematic extrapolation. Variations may then be generated by diverting expenditures on one subsystem, say attack aircraft, and applying the amount to other subsystems,

say interceptor and reconnaissance aircraft. If the quantitative change in effectiveness associated with each decrement or increment is computed separately, we have estimated portions of the familiar marginal productivity functions of economic analysis (reference (a)).

The construction and analysis of forces in this fashion makes it clear that in a comparative evaluation of such proposals it is their differences in resource drains that count. Errors and omissions in estimating costs that are invariant among structural variations do not bias a comparison. But these costs must be estimated if the result is to contribute to the "higher-order" allocation between force levels for different missions in the military sector.

This is why a partial or comparative systems analysis usually demands substantially more than the bare-minimum cost analysis for the comparison alone. Program decisions and budgetary implementation within the Department of Defense require exposure of the full incremental cost of a candidate system and, ultimately, programmed over time. Further, the wider the scope of alternatives evaluated in a particular systems analysis (e.g., Navy vs Air Force systems) the larger will be the portion of costs that differ among systems, and the more extensive is the minimal cost analysis directly required for the partial analysis.

A selection of a system affects the flow of only a portion of defense resources. The cost estimates for a systems analysis should identify incremental resource costs for each system proposal. A proposal should be charged with all the costs which are required for achieving the measured mission effectiveness, but exempted from charges that attach to effectiveness in an unevaluated mission or in another era. By this principle, an effort to attach costs to effectiveness can succeed in practice only if the cost analysis is intimately governed by the type and time-profile of effectiveness that is evaluated. This is now conventional wisdom in defense analysis. The difficulty lies in measuring additional resource claims.

Cost measurements employ monetary prices and for most issues there is no better way. An exception occurs in tightly-constrained operational analyses of tasks in which the physical quantities of certain resources are absolutely fixed. If certain resources are to be employed only in the analyzed task with no additional quantities available from other uses, monetary prices observed in exchange transactions elsewhere are irrelevant. Without substitutability of resources among uses the suboptimization is a purely internal maximization, subject to the requirement that it is consistent with broader defense objectives.

With this exception (ignoring imputed costs for the moment), system and cost analysts in practice employ actual money prices observed in exchange transactions. Resources claimed by a selected project must be paid dollar prices sufficient to attract and hold them to defense from their alternative opportunities. Prices thus express fundamental economic costs of defense in our

economy, as well as constraints on a decision-maker's ability to achieve objectives. (At the end of this chapter the situation is cited in which observed prices are imperfect reflectors of true, alternative costs.)

The cost analysis of systems studies may be given two dimensions: (1) Synthesis and summary of full system costs for the comparison of alternative force-mixes. (2) Research on component, subsystem, and associated costs, - work that involves specific development and application of cost estimating data and techniques.

In a systems study analysts find themselves simultaneously resolving issues in both dimensions. For each force variant the analysis estimates the resource combinations and associated cost of the structure providing the capability. The cost analyst should work with, rather than simply transmit exhibits to analysts who structure and compare the effectiveness of candidate alternatives so that the cost of each system is properly estimated and summarized in relation to the effectiveness that results.

SYNTHESIS OF SYSTEM COSTS

There are many ways of splitting and then summarizing a total system cost. The process ought to be inspired by a simple theoretical guideline. If we had the power to make good estimates of all the necessary variables and parameters, and the time to do so, we would determine for each course of action the time-pattern of mission effectiveness and the time-pattern of associated costs that achieve it. Further, if we could demonstrate the appropriateness of some rate of discount with which to reduce magnitudes in different years to equivalence, we could discount future terms to calculate present values of cost. Then we could seek the preferred effectiveness for a given present value of cost, or the minimum present value of cost for any given stream of effectiveness.

In practice, the application of this model is not easy. Various expedients and rules of thumb are used. The authors have at some time used many of these and been tempted by most. We will highlight some problems and practices in cost analysis with an example that introduces a discussion of synthesis and estimation.

An Example of Force Costs

Both ground systems and air systems contribute to the same mission capability. Currently there are 40 ground units and 12 air units in the force structure. Expansion of the capability to a higher level is considered, including either improved ground or air units, or both. For simplicity we construct three alternative incremental mixes only. The example illustrates the problem of comparing costs if the forces are estimated to have equal effectiveness, and suggests the necessity of reconstructing the illustrated incremental forces if they are to be made equal-cost in some acceptable sense.

Each mix is an increment to the current force of 40 ground and 12 air units. Mix I is a pure ground increment, mix II includes both ground and air units, and mix III is a pure air increment. They are as follows:

	I	II	III
Ground Units	60 (+20)	50 (+10)	40 (+0)
Air Units	12 (+ 0)	14 (+ 2)	17 (+5)

The "effective" life is estimated to be 15 years for new air units and five years for new ground units. Non-recurring costs per unit of air and ground are estimated as functions of the volume produced. As shown in figure 1, per-unit initial investment costs decline when production efficiencies are achieved at increased volume. The recurring cost is estimated to be a constant $50/unit/year for air and $10/unit/year for ground.

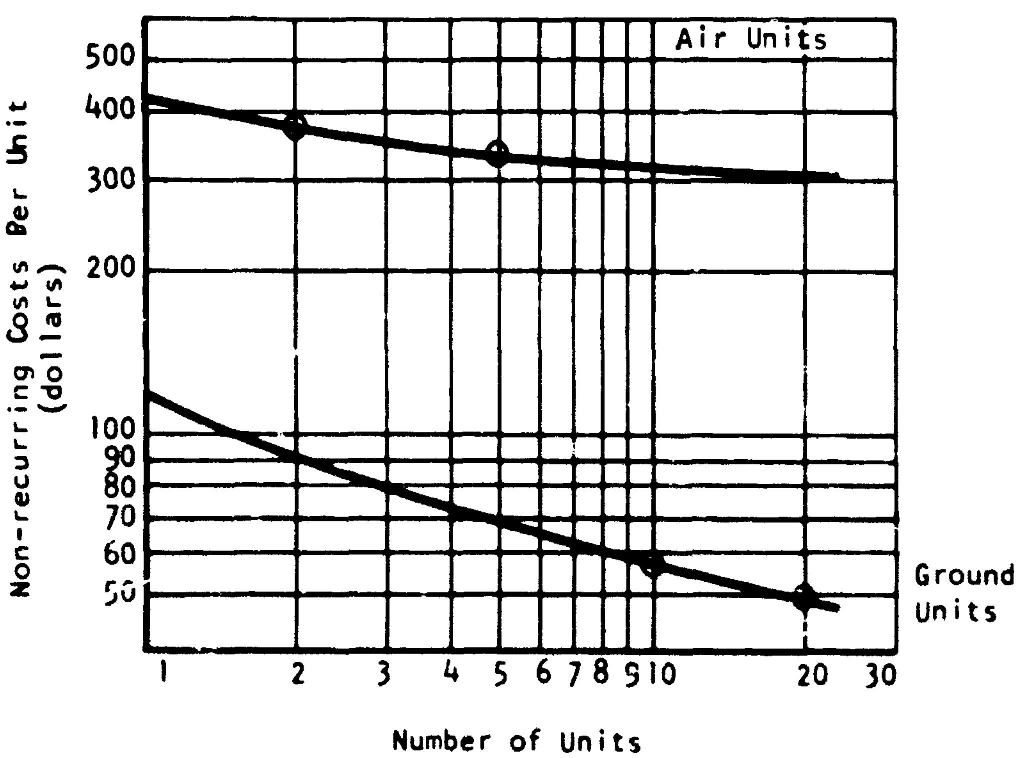

FIG. 1: CUMULATIVE AVERAGE COSTS OF NEW UNITS

Expenditures are then summed to get a total cost for each force-mix shown in table I.

TABLE I

TOTAL COSTS

Mix / No. of Years	I [20 Ground 0 Air]	II [10 Ground 2 Air]	III [0 Ground 5 Air]
5	1975	2311	2900
10	3950	3886	4150
15	5925	5461	5400

If effectiveness is desired over five years only and total costs are compared only for that interval, the pure ground system has the lowest cost. If the three forces promise equal effectiveness over five years the air units cannot compete because of their high non-recurring costs.

Suppose effectiveness is wanted beyond five years but the cost comparison is limited to the short interval. If air units are selected now rather than ground units, at the end of five years such air units would then provide a remaining effectiveness that permits the avoidance of later expenditures that otherwise would be necessary for replacements of any ground units if selected now. A side calculation may take into account this end-of-study "remaining value" of durable systems.

It can be shown that the remaining value of air units actually in the inventory five years hence, is the excess of subsequent expenditures (beyond five years) that would have been incurred on ground units (if selected initially) above subsequent expenditures on air units that were selected initially, given that either selection can provide a specified effectiveness. This excess is the net expenditure that can be avoided in the period after five years if air units, rather than ground units are selected initially to provide effectiveness over the entire longer interval.

If remaining value is properly accounted for, the time horizon must be extended as a side calculation and the remaining value then quoted separately, accompanying the five-year total costs. It is simpler to extend the time horizon for the main study to include future procurement and operation of ground units as replacements. As the study interval lengthens the remaining value of air units is deferred and reduced. It vanishes if an interval is constructed so that across all three structures the end of every chain-of-assets coincides. This interval in the illustration is 15 years. For this horizon, total costs of II and III

are about equal and below the total cost of the pure ground increment. The relationship between total cost and time is shown in figure 2.

Clearly the greater early costs in forces II and III above force I are more than counterbalanced by lower costs in the future. These are undiscounted costs. Perhaps the discounted 15 year costs are desired. The present values of I and III are equal at a discount rate of approximately 8 percent. For I and II, the rate for equating present value is higher, approximately 13 percent, because the penalty in early expenditure of II is much smaller than of III.

Quantitative differences in total cost are dependent upon the estimates in the various cost categories. If the recurring cost of the air system is smaller, $35/unit/year, cumulative force costs are shown in figure 3. Force-mix I still has a significant but narrower cost advantage at five years. Differences at 15 years are now much larger. A discount rate of 20 percent is now required to reduce the 15 year cost of I to equality with that of III, and 25 percent makes the present value of I and II equal.

Cost Categories

A useful step in cost analysis is the preparation of appropriate categories of relevant costs. Cost categories assist in separating expenditures into quasi-homogeneous types that are distinguished by particular resources, activities, and by the causes that determine their amount. Usually costs will divide according to whether they are non-recurring or recurring, and into major categories such as R&D, investment, and operations and maintenance (reference (b)).

Elements similar to those listed in table I are usually included in a weapon system cost analysis. The three major categories follow a chronological order: however, there is usually some time overlap. Investment expenditures occur before the completion of research and development, and operations expenditures begin before the delivery of all items of prime mission equipment.

There are situations where a categorization exactly as shown in table II is misleading. An example is a study of alternative means of placing payloads into orbit around the earth. In most military systems the cost of launching rockets would be considered an initial investment. However, for keeping earth satellites continuously in orbit boosters would be launched periodically. If they are non-recoverable, their costs should be treated as operations costs similar to other recurring costs.

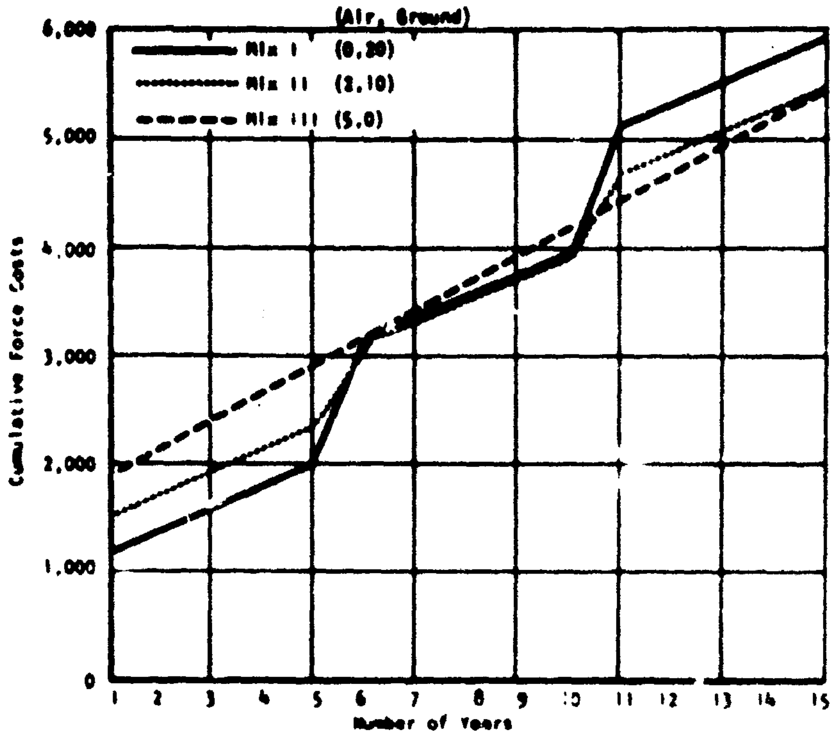

FIG. 2: CUMULATIVE FORCE COSTS, HIGH AIR SYSTEM OPERATING COST

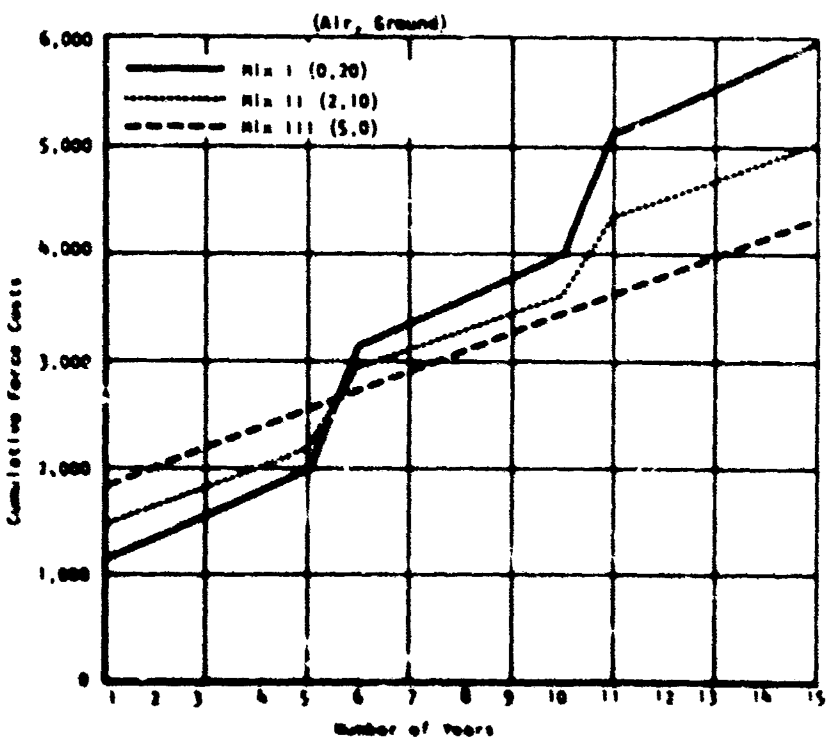

FIG. 3: CUMULATIVE FORCE COSTS, LOW AIR SYSTEM OPERATING COST

TABLE II

TYPICAL CLASSIFICATION OF WEAPON SYSTEM COST ELEMENTS

A. Non-Recurring

I. Research and Development

1. Preliminary Research and Design Studies
2. Design and Development (Of Subsystems)
3. System Test (Of Complete System)

II. Initial Investment

1. Prime Mission Equipment
2. Support Equipment
3. Initial Spares, Spare Parts and Stocks
4. Initial Training
5. Initial Travel, Transportation, and Miscellaneous
6. Military Installations

B. Recurring

III. Annual Operations

1. Pay and Allowance
2. Equipment and Installations Replacement
3. Equipment and Installations Maintenance
4. Replacement Training
5. Consumables (e.g., fuel, oil, etc.)
6. Recurring Travel, Transportation, and Miscellaneous

The cost of altering ships and their weapons and electronic systems for the purpose of improving capability presents a problem of categorization. During her lifetime, a ship may be altered several times but at irregular intervals because major alternations are not physically necessary to achieve the major capability of the ship. Cost models which include an estimate for alterations averaged as an annual expense will be inappropriate where the cost of operating ships for their full life-times is not at issue. Cost categories should depend upon the application and each analysis should assess its special needs.

Time-Patterning the Estimates

Another virtue of cost categories is that they assist an analyst in focusing his estimates over a series of future years. It is useful to disaggregate considerably in order to make credible estimates of the annual pattern of costs. When similar costs are more remote and uncertain, in the case of advanced proposals, this detail is less useful.

Estimates of cost time-streams serve several purposes: (1) Some elements of cost are typically deferred and sometimes omitted from analysis unless the procedure calls specifically for time-patterning costs; examples are infrequent ship modernizations or aircraft model improvements. (2) Decision-makers must anticipate when and what types of expenditures will occur, because the budgetary process authorizes expenditures annually and by specific types. (3) Decision-makers are not indifferent between expenditures in different years even if the arithmetic total over a period is given. Some of the most important substitution possibilities within defense are substitutions over time, - e.g., maintaining existing forces longer and developing replacements later, or vice versa.

Time Horizon and Remaining Value

The study interval is appropriately determined within the individual analysis. No general convention or rule of thumb, apart from the purpose of the analysis, can specify it except arbitrarily. Within the analysis, cost and production feasibility considerations alone cannot specify it. Analysts should confront the questions of what the characteristic threat is, what types of capability may met it, how long each operational system may be expected to provide effectiveness, what the prospective future equipments and methods may be, and when development may provide them.

As illustrated earlier in the example, some systems may promise further effectiveness beyond a chosen time horizon. This may be credited to the air units at a five-year horizon by estimating expenditures in the still-farther future that may be avoided if those units are then in the inventory. If assets are not expected to be very effective in the primary mission there may be a secondary role where their availability will permit certain expenditures to be avoided.

Even when longer time-horizons, such as 15 years, are employed we may expect assets of some forces to be effective beyond the study interval. We usually lack reliable evidence or techniques for estimating remote effectiveness and the remote avoidable expenditure the assets permit. Cost analyses sometimes employ the arithmetic of amortization as an implicit predictor. Care must always be taken to avoid substituting simple arithmetic, because it is simple, for attempts at estimation or analysis. However, even an arbitrary accounting method will frequently give a far better estimate of remaining value

at the end of a study interval than if the question is ducked and the value set at zero. One can avoid the question but he cannot thereby avoid making an implicit estimate - and it may be a bad one.

A related issue involves existing assets proposed for use in a system under evaluation. Is such equipment to be treated as free when "inherited" by a system, or not? Almost any comparison of alternative systems involves existing assets, although many will be specific to a particular purpose with no meaningful alternative use. Nevertheless, rather than assume this, the analysis should ask if the asset is useful for another objective and what the maximum expenditure which could be avoided by its application elsewhere may be. This is the (alternative) cost of "assigning" it to a system in the analysis. If this factor becomes important the study may consider a widening of scope in an attempt to include more types of effectiveness.

Current alternative values and future remaining values are imputations. Estimates of net costs involving imputations appear less straightforward, and therefore less reliable, than estimates of most explicit costs. To be convincing, an estimate of remaining value must demonstrate that the asset structure promises a desired effectiveness in some mission in the farther future. It is little wonder that cost analysts are unenthusiastic about imputations that rest on effectiveness measures. Yet these imputations do not introduce, but merely underscore, an analytic difficulty of effectiveness measures.

Time Preference

Economists differ in their interpretation of what economic analysis implies about applying a discount rate in comparing non-marketable projects such as defense. One opinion says to discount at the rate of interest on "comparable" types of investment in the market economy. The rationale is that when we extract resources to the non-marketable sector from other uses we cannot be efficient unless we select only from the systems that are as productive of future benefits, or as saving in future expenditures, as successful investments in the private sector.

Another opinion says that economic analysis cannot be extended to demonstrate the achievement of efficiency from testing non-marketable investments with the market rate of interest appropriate for testing productive investments by individuals who compete for resources under private property. Although this opinion can be quite unsparing in criticizing unevaluated non-marketable projects, it rejects the direct transferability of a market rate of interest to assist evaluation of these activities (reference (c)).

Another question concerns discounting cost streams "to take account of risk". Loading the discount rate with a factor "for risk" is quite perverse if it is intended to correct for doubts about the relative cost estimates in the systems studied.

This is shown by considering two estimated cost streams for producing a given effectiveness. Suppose we know from empirical evidence that cost estimates for the farther-future become less reliable. Applying a discount rate to streams of single-valued, annual cost estimates reduces remote costs more than early costs. The discounting operation thereby biases choice toward projects with relatively large later cost estimates, the more uncertain alternatives. The bias would be still stronger if an attempt is made to account for differential estimating reliability among entire streams by discounting riskier cost streams at higher rates.

Adding a risk factor to a discount rate is sometimes suggested for a different reason: our inability to anticipate options we later find attractive. There is much experience in which options were initially unanticipated, because of either ignorance or myopia concerning the real nature of the threat or technology, and later discovered to be attractive as information grew. Future evidence, if not too late to impact a selection, will cause us to reevaluate an initial selection and perhaps to abandon it. Will loading comparisons with a discount rate aid such sequential decision-making? In a sense, yes, because it shifts choice away from projects with relatively heavy early costs, thereby dampening early commitments. It is, however, hard to imagine anything more arbitrary than loading a discount rate as a device to promote incremental spending in search of reliable information on obscure benefit and costs.

Cost-Summarizing Techniques

A number of conventions for summarizing costs may be found. Several that have been employed in studies are defined here (reference (d)).

Five-Year System Costs: This convention arithmetically sums the R&D, initial investment, and five times the annual cost of operating the system at a specified level. Remaining values at the end of five years of level operations (which may be 7-15 years after the initiation of R&D) are excluded. Also excluded are "build-up costs", i.e., the operating costs incurred during the phase-in period before the system reaches its full force.

Period Outlay: Build-up costs are included and outlays are time-phased, either by year of obligation or expenditure. In some studies, remaining value has been referenced simply by listing the age structure of assets as of the study's cut-off date.

Net Cost: This technique attempts a measurement of remaining values. Specifically, it gives effect to unequal useful lifetimes among the principal assets both within and across force-mixes. The time pattern of costs is estimated, including a remaining value of assets at the cut-off date. This is then subtracted from the estimated expenditures to get a "net cost".

Equal Life-Lengths Cost: An approximate time period is computed so that across all force-mixes the end of each estimated chain-of-assets roughly coincides. A special case occurs when in each chain the replacement equipments are expected to have the same useful lifetime as initial equipments in the chain. This is illustrated by the five-year replications of ground units in the example above.

There has been over emphasis of the five-year system cost technique in the past. Because of its exclusions, it can be misleading in some cases. But this is not meant to suggest that the five-year cost has no place in cost analysis. The five-year system cost estimate is useful in a pre-development analysis of systems that rely upon technological advances far in the future. An aerospace plane or a nuclear powered missile impose requirements and associated costs that cannot now be estimated with accuracy sufficient to warrant the use of detailed cost summaries.

For less advanced systems nearing procurement, whose specifications can be estimated with more accuracy, one should not ignore the time pattern of costs, unequal lifetimes of alternatives, build-up costs, etc. Feasible production, construction, and introduction schedules should be examined more carefully. A satisfactory resolution should be found for the question, "Are we examining optional mixes having a useful capability over the same time period?" At this stage, reliance on a short study interval and effectiveness measurements for only one nominal future date can obscure real issues involved in selection of a production program.

TOPICS IN COST ESTIMATION

Broadly, there are two types of decisions in which systems analyses assist: force-structure procurement and development planning. The following topics relate to both.

Use of Historical Data

Although sunk costs are irrelevant to evaluations of future options, records of past costs are indispensable as a base upon which estimates of future costs and system characteristics are projected. Prospective systems usually involve components and operations that have close analogs in the past or present. Past or current experience also warns us of pitfalls, delays, and improvisations having substantial cost consequences.

It takes years to build a good library of data on both procurement and operational aspects of defense programs. The task is riddled with frustrations. Government record-keeping has always been adapted primarily to assuring fidelity to financial authorizations. These records are not ordinarily useful in relating means to ends - in evaluating activities by their claims on resources and their

contributions to some agreed objective (reference (e)). Enormous efforts have been, and are still, required to adapt them to this function.

Defense-related cost data are often treated as sensitive information by government agencies and as privileged information by industrial contractors. (This is unrelated to military security.) One effect is to reduce the information available to cost analysts outside the government proper. Although certain information is rightly privileged to private enterprise, impediments here are gradually eroding. The military services have instituted publication of general program-planning and cost factors. Contractors are required to submit certain cost reports depending upon the type of contract. These are very useful sources of data but require much evaluation. There is often inconsistency across sources. An investigator who wants detail usually must probe behind the reports for it.

Cost-Quantity Relationships

Hardware procurement costs have received more attention than operating costs. The chief relationship established for major items of military hardware is the dependency of total production cost per unit upon volume of output. Cost per unit is observed to decline with increased production over an extended range of output. This has been observed in the airframe industry and it has found application elsewhere among major equipments produced in quantity (reference (f)). Marked reductions in man-hours used in production of successive lots are observed. One explanation is "learning". In the course of operations, workers and supervisors learn the process and how to do it better. Data on other inputs also indicate a similar effect for materials. Cost analysts have by now fitted a number of functions relating cumulative cost to cumulative quantity.

Another influence of total volume on cost is difficult in practice to separeate from the first. In planning production there is an initial choice of how much investment in plant, equipment, and special tooling to undertake. For a planned cumulative volume, trade-offs are possible between initial investment costs and subsequent operating costs. As the intended volume (for which initial plans are made) increases over a significant range, a firm can plan the production method to select more diverse and durable equipment and tooling, thereby lowering per-unit costs of production (reference (g)). This proposition has received less empirical testing than "learning", but it is familiar to defense contractors who produce specific equipments to order. It may deserve more investigation in planning the volume production of items such as ships or the huge new C5A transport aircraft. Cost analysis in this context strives to reveal the efficient (economical) technology to employ in major defense production.

Estimating Procedures

For an operational (or retired) aircraft an analyst may find production costs on, say, four to eight delivered lots produced by a specific firm. In estimating future costs of a proposed aircraft with different attributes, this information represents one observation only. The objective may be to estimate the future research and development, procurement, and operating costs of a proposed aircraft that flies faster, lands slower, carries more payload, and has an all-weather capability. Such an aircraft will attempt aerodynamic advances. It will weigh more, have bigger and perhaps more efficient engines, use different alloys, mount advanced sensors and weapons. Its configuration may imply different maintenance practices. Perhaps its operational mode implies different attrition. The cost analyst enumerates the delivered aircraft that differ in these distinctive factors but are sufficiently homogeneous in other respects so that their recorded costs may bear directly on estimation for the new vehicle. If he finds four to eight observations on other "similar but different" vehicles he feels an embarrassment of riches in a predicament that apalls most statisticians.

In fact, there is perhaps now more good information on aircraft and their components than on any other type of major vehicle or equipment. There is now enough data in some areas to warrant use of multiple regressions. Estimated regression relationships for airframes, engines, ships, and certain aspects of aircraft and ship maintenance have now appeared (reference (h)).

These must be tested by their fruitfulness - do they assist us in better cost estimating than we perform without them? Few, if any, of the "samples" can be said to exhibit the statistical properties for which regression is derived in statistical theory. The application of statistical estimating relationships to an estimating problem must be made with caution, particularly when forecasting beyond the limits of the data. An experienced researcher will also employ judgment based on information "outside" the regression if the subject forecast is for an item that differs in important attributes from the events used in estimating the regression.

Most cost estimates must be accomplished with too few observations on particular subsystems or components to permit regression estimation of relationships. When data are sparse the estimator may use two types of procedures.

First, he may look for one or more close analogs for which information is available. For example, in estimating the cost of a new re-entry subsystem he will examine in some detail the cost of the one or two recent vehicles that resemble the candidate design. In such procedures it is common to try to account for systematic effects of different components on the total cost of the vehicle, and to treat cost elements such as labor, material, and engineering-hours separately. Experience has shown, however, that detailed estimates can still be bad estimates. For advanced proposals, this is more likely if an analyst attempts to relate estimates exclusively to forecasted component weights rather than to prescribed performance. Detail frequently implies credibility to the uninformed. Perhaps this accounts to some extent for the detail one often finds

in cost estimates. If the estimation exhibits are very detailed it can be difficult to distinguish a paucity from a plenty of reliable and independent observations.

By contrast with the specific analog, a second approach when independent observations are sparse is to use cost information that is aggregated to a higher level. Where information has not been disaggregated to relate it to characteristics of individual units, it is often available from budgetary exhibits on an overall basis. This type of information has been employed in estimating costs of operation and support. Here, too, cost factors are frequently constructed, such as cost per military man. This factor is found from an aggregate budgetary expenditure for pay and allowances, and an aggregate manpower figure.

If applied to quasi-homogeneous categories of manpower or materials, simple cost factors provide satisfactory estimates for most comparative purposes. It should be emphasized that this is a procedure solely for estimating costs of given, specified methods of employing these resources. It says nothing about the efficient ways of combining manpower and equipments in defense activities. This is a different and more penetrating question. If analysis is to provide findings on this question, it must attempt experiments or simulations that actually vary amounts and qualities of manpower in combination with materials and equipments.

Early Estimates for Advanced Systems

Defense cost analysis is now old enough to have a histroy. A review of the record of approximately the first decade of cost estimating, a period corresponding closely to the nineteen-fifties, shows a variable performance. There is a bias toward underestimation (reference (i)). The degree of underestimation, and the variance of estimation errors, both seem to be related to the earliness of the estimate and the type of proposal. Differences between early estimates and ultimately realized costs have been small for systems where attempted advances were modest. These include, for example, non-combatant ships and cargo aircraft. Errors in early estimates are systematically larger for new combat aircraft with advanced radars, communications, and weapons; and for advanced rocket propulsion and guidance systems.

Aside from the partiality and advocacy which to some degree affect all forecasters, what accounts for this record? Two major areas of uncertainty are distinguished. One is uncertainty concerning the time and difficulty to develop for procurement a design and configuration that ultimately achieves a promised performance. The other is pure estimating uncertainty concerning the costs of delivering any specified physical configuration. There is a good prospect of improving this development-and-cost estimating record, for proposals where attempted technological advances are great, by focusing early estimation on information that relates cost to advances in performance instead of costing someone's early design specifications.

Why do we want early cost estimates for proposals "promising" great advances? At this stage the problem is far different from procurement selection where both contractor and proposal must be selected for large production runs. By contrast, research and development is a process of securing information about the real capability of proposers to deliver performance, - how, when, and at what cost. It is a process that buys this information incrementally, year by year. It would be foolish early in pre-development to act as if we can then estimate each proposal's cost reliably enough to make a single, terminal selection without component and subsystem development yielding test data.

The reason for wanting very early estimates is that development resources also are constrained. Even if we intend to buy partial or sequential development on similar proposals we must select these from a range of aspirants. The cost estimate is one aid in preliminary evaluation of development proposals. As estimates are revised when confronted with experience they become credible for force-structure analyses leading to production decisions.

Sensitivity

All studies include doubtful features that cannot be satisfactorily specified or resolved quantitatively within the study (reference (j)). The character of the threat, the detection range of a sensor, the effectiveness of an aircraft against a target, the cost of the needed support activities may all be examples. Each can be varied in magnitude to see how the final quantitative results are influenced by, or are "sensitive" to, possible variability in the doubtful factor.

This exercise can be very revealing. In a complicated analysis it can greatly reduce the obscurity between assumptions and findings by showing separately the features to which results are and are not responsive. We can thereby indicate where the more costly "mistakes" may be, even if we cannot estimate a strict statistical reliability. Uncertainties bearing heavily on results become options for further research and experiment. This must be the path of progress in systems analyses. Most formal studies are more synthesis than analysis. Each synthesizes much existing knowledge, adds a bit to the fund, or helps to identify efforts that will.

SOME AVENUES FOR FURTHER WORK

The broad and pervasive area called "support" presents difficult problems in measuring resource claims. Apart from the question of management efficiency, and how it may be improved, it is difficult simply to identify the incremental (decremental) physical quantities of many resource services associated with incremental (decremental) achievements in system effectiveness. When we look behind the warfare system "identifiers", i.e., the hardware items, one finds substantial investment and operating costs for "support" activities required to sustain their capability. Specific and necessary services are partially obscured

in the supporting military structure. Although the current Department of Defense programming system has made a contribution to unravelling this structure, the format does not automatically answer questions a systems analysis must raise concerning which portions of support activities are incrementally linked to possible changes in a system or force structure.

Another difficulty in specifying relevant costs occurs when a system directed to one objective would, if selected, increase effectiveness or reduce costs of another mission. In economic analysis these are external economies or spillovers. Spillovers within the market-and-price system consist of items of benefit or cost that are experienced by others as a result of one decision-maker's choices, which he does not take into account, and for which others are not charged or recompensed. Although in different form, essentially the same phenomena are found in government, including the defense sector. Spillovers to other activities are likely to be larger the narrower the scope of alternative systems that enter a comparative analysis and, thus, the larger the range of other activities that employ similar resources or provide related effectiveness. Hence it is often desirable to attempt to broaden a study to include more types of effectiveness and reduce the allocation of costs among narrow missions.

For some resources, including categories of manpower, there are ceilings on prices. These and other resources are rationed or assigned among alternative users in defense on some basis other than price-expressed valuations. Assigned users do not have to pay as much as would be required to secure them from other abortive claimants through open bidding. If prices are fixed or nonexistent, neither the external acquisition nor internal allocation processes yield good information on relative productivities in different uses and, thus, on true alternative cost. In this environment, further exploration of technological possibilities for substitution among manpower and equipments in defense programs will very likely reduce costs or improve capabilities. There is a growing awareness of possible payoffs in efforts to analyze manpower utilization and to improve the quantification of system claims on manpower.

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13. ABSTRACT

Two principal dimensions of system cost analysis are addressed. First, the comparative analysis of alternative systems requires a method of structuring and synthesizing cost estimates in order to reveal both the total costs of achieving effectiveness and the significant differences to be found among various force-mixes. Second, the methods of estimating particular costs are evolving from a history of inappropriate or inaccessible data and great uncertainty concerning the time and costs of ultimately achieving demonstrated capability. Several important avenues for further work are discussed.

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